PB85-204741

Cost of Selected Trap-Oxidizer System Components for Heavy-Duty Vehicles

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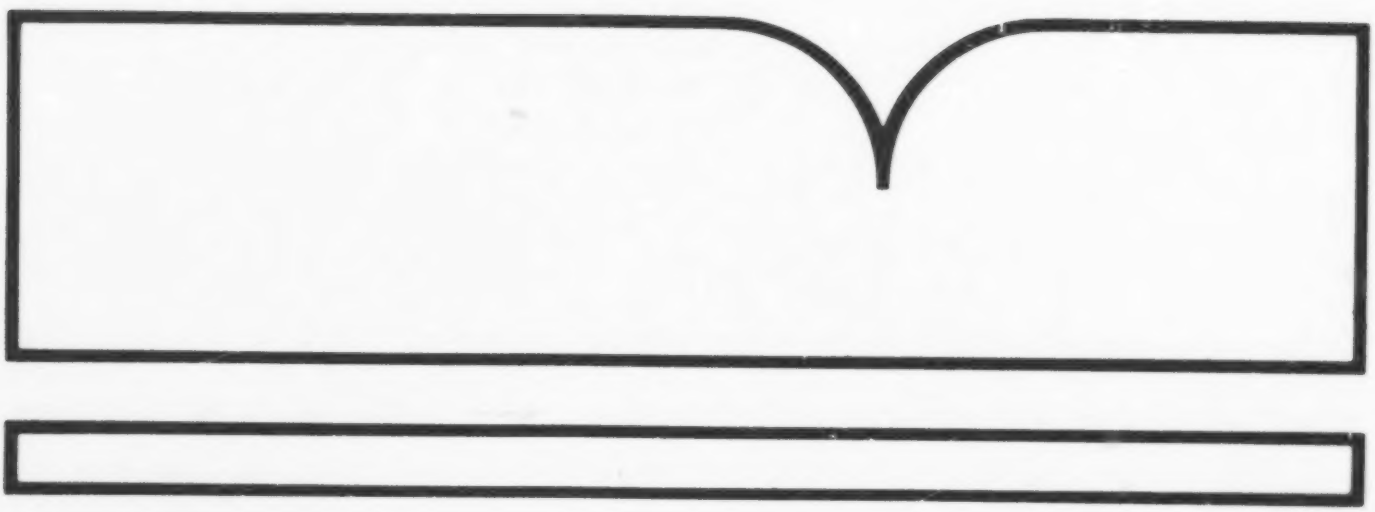
Prepared for

Environmental Protection Agency, Ann Arbor, MI

28 Sep 84



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1. REPORT NO. EPA/460/3-84-18	2.	3 PB85-204741
4. TITLE AND SUBTITLE Cost of Selected Trap-Oxidizer System Components for Heavy-Duty Vehicles.		5. REPORT DATE September 28, 1984 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Jack Faucett Associates, Inc. 5454 Wisconsin Avenue Suite 1155 Chevy Chase, Maryland 20015		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. 68-03-3200
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency Office of Mobile Sources Standards Development and Support Branch Ann Arbor MI 48105		13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

This report describes the estimated costs of selected trap-oxidizer system components for heavy-duty vehicles. This report also provides the rationale used for selecting the cost estimation approach and the actual cost estimation methodology used. Also included is the description of the trap-oxidizer systems considered and the cost of the components.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution Diesel Engines Exhaust Emissions Particulates	Heavy-Duty Engines Diesel Particulates	

18. DISTRIBUTION STATEMENT Release Unlimited	19. SECURITY CLASS *(This Report)* unclassified	21. NO. OF PAGES 28
	20. SECURITY CLASS *(This page)* unclassified	22. PRICE

EPA Form 2220-1 (9-73)

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NATIONAL TECHNICAL
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EPA 460/3-84-18

COST OF SELECTED TRAP-OXIDIZER SYSTEM COMPONENTS FOR HEAVY-DUTY VEHICLES

Final Report

September 28, 1984

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I. INTRODUCTION AND RATIONALE USED FOR COST ESTIMATION

A. Background

The use of trap-oxidizer systems may become a necessity on heavy-duty vehicles in order for manufacturers to meet future diesel particulate emission standards. An important factor leading to the development of such standards is the cost of such systems and the resultant economic impacts. This report presents estimated costs of selected trap-oxidizer system components for heavy-duty vehicles. The effort was conducted for Jack Faucett Associates under their prime contract with the U.S. Environmental Protection Agency (EPA Contract No. 68-03-3200).

The remainder of this section provides the rationale used for selecting the cost estimation approach and the actual cost estimation methodology used. The remaining sections of the report describe the systems considered and the components that were costed. The systems addressed include a diesel fuel burner regeneration system (Section II), a system incorporating a turbo bypass valve and associated piping (Section III), and a ceramic fiber trap, metal catalyst regeneration system (Section IV). In addition, costs for several general components for trap-oxidizer systems are described in Section V. Finally, the sources of information used are noted in Section VI.

B. Cost Estimation Considerations

Developing engineering estimates of finished product costs is an inexact science similar to other types of forecasting commonly done (i.e., economic, demographic, weather, etc.). Engineering cost analysis has an advantage over most other types of forecasting in that more information is usually at hand and very analogous activities have been performed in the past for which information is available. This particular task (cost estimation of heavy-duty diesel vehicle particulate trap system components) is complicated by the fact that the components specified are not currently (nor have they ever been) in production. The best approach in this situation would have been to perform a rigorous "bottom-up" engineering and cost analysis which addressed each part of every component. However, the time and effort committed to this task

precluded such a rigorous approach. Additionally, the present situation is an inappropriate time to perform a rigorous engineering and cost analysis of heavy-duty diesel vehicle particulate trap components for the following reasons:

- Production system configurations have not yet been finalized. The current state of heavy duty diesel vehicle particulate trap technology is not at a level such that definitive decisions can be made about what components should be used and how they should be configured. Components and systems will require testing to prove the engineering validity of their use in production vehicles.
- The costs of production components depends greatly upon the volume of components produced each year. Each of the particulate trap systems has unique components. An informal estimate indicates that there are at least eight independent manufacturers supplying heavy vehicles in the United States at this time. Conceivably, each of those manufacturers could design diesel particulate trap systems that are unique to the extent that there is no commonality of parts among manufacturers. This could greatly impact the cost of individual components, even if they come from a single supplier.

Because of these reasons, the project team devised and used the cost estimation methodology described in the following subsection. It is believed that the methodology employed best suits the requirements and is appropriate to the technology at its current state of development.

C. Cost Estimation Methodology Used in This Analysis

The method used to generate the cost estimates draws heavily on previous experience estimating motor vehicle new component costs. Experience has shown that the most straightforward approach is to utilize analogous hardware for cost estimating with several industrial or commercial sources contacted for cost quotations. In addition, the previous work of L. H. Lindgren[1] is used as appropriate as a source of cost data for specific components or as a

reference for acceptable "markup" information about the automotive industry. In order to establish a common basis for the cost estimates the concept of a manufacturer's price equivalent (MPE) was used. This approach provides a common "baseline" cost that is representative of that charged by the manufacturer for a specific component or part of the vehicle. Figure 1 displays the chain of distribution from component manufacture through purchase in an assembled vehicle or as a spare part. An example of the cost adjustment process for a specific part, a computer-controlled vacuum diaphragm actuator, is also shown in the figure.

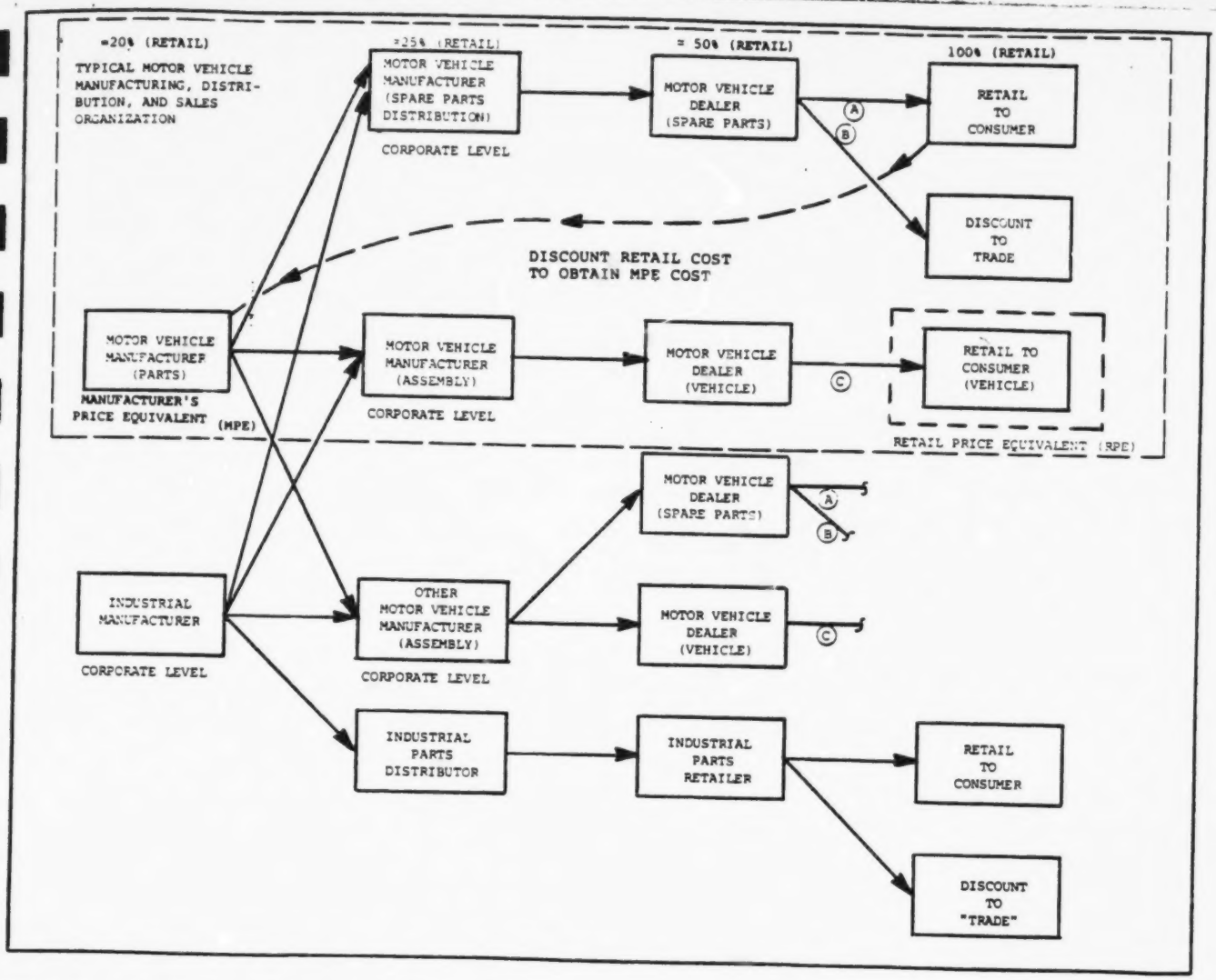
The manufacturer's price equivalent was then used to develop a retail price equivalent (RPE) using the following formula developed by Lindgren.[2]

$$\text{Retail Price Equivalent (Component price to consumer when buying an assembled vehicle)} = \left\{\left[\text{Direct Material} + \text{Direct Labor} + \text{Fixed \& Variable Overhead}\right] \times \left[1 + \text{0.20 Corporate Allocation} + \text{0.20 Supplier Profit}\right] + \left(\text{Tooling Expenses} + \text{Land \& Building Expense}\right) \times \left\{1 + \text{0.20 Corporate Allocation} + \text{0.20 Corporate Profit} + \text{0.40 Dealer Overhead \& Profit}\right\} + \text{R\&D} + \text{Tooling Expense}\right.$$

or in abbreviated form:

$$RPE = \underbrace{\{[DM + DL + OH]\ [1.4] + TE + LBE\}}_{\text{Manufacturer's Price Equivalent (MPE)}^{(2)}}\ \underbrace{\{[1.8] + RD + TE\}}_{\text{Markup, Overhead and Other Adjustments}}$$

MPE is equivalent to the plant or vendor selling price used by Lindgren[2] and is approximately one-fourth to one-fifth of the aftermarket selling price based upon standard aftermarket discount data in other references. By definition it includes tooling



EXAMPLE: Estimate for Computer-Controlled Vacuum Diaphragm Actuator

ASSUME: Assembly analogous to computer-controlled EGR valve assembly.

REPLACEMENT COST: $50.00-$70.00, depending on specific manufacturer and application. (purchased from dealer)

Adjustment from retail to Manufacturer's Price Equivalent (MPE)

MANUFACTURER'S PRICE = ($50.00-$70.00) x (MPE Adjustment Factor)

= ($50.00-$70.00) x (0.25-0.20)[a]

= $10.00-$18.00

[a]MPE Adjustment Factor from Reference 1.

FIGURE 1. SCHEMATIC OF COMPONENT CHAIN OF DISTRIBUTION AND EXAMPLE OF MANUFACTURER'S PRICE ADJUSTMENT PROCESS

expense, material, labor, applicable overhead and land and building expense.

If it is assumed that R&D and tooling expenses per specific component produced and/or installed by manufacturers are zero, then RPE = 1.8 MPE. If the component will require certification and an R&D effort before production, R&D costs may be amortized over a production run of three to five years. The R&D expense usually applies to the use of the component in an assembly that requires testing. For the particular component under consideration here, a specific R&D or certification cost cannot be directly allocated. This same logic can be applied to the tooling expense considered in the second factor of the RPE equation. This tooling expense refers to the tooling, jigs, and fixtures required for component assembly into a system or that system into the vehicle. As a result of this categorization, this tooling cost cannot be directly associated with the component but should be associated with the assembly or subsystem to which it belongs.

As a result of not actually costing the specific trap regeneration systems, but only several key components, the R&D, tooling, vehicle assembly, and engine modification expenses associated with the system have not been estimated. The reader is cautioned in this regard that the sum of the components of a specific system will not truly represent the RPE system cost without these additional elements. Thus, the RPE of a total system can be regarded as:

$$\text{RPE of Total System} = \Sigma \text{RPE}_{\text{Components}} + \text{R\&D} + \text{Tooling Expense} + \text{Engine Modification Expense} + \text{Vehicle/System Assembly Expense}$$

Another key area of some concern in conducting the cost estimation was the fact that many of the components estimated reflect high production, while others would only be built in the approximate quantities required by the truck manufacturer to meet vehicle production demands. Volume production obviously affects the manner in which a product or component would be most economically

manufactured. The larger the quantities, the more automation, less manual work, and often reduced raw material costs are realized, and the unit cost will drop with high volume production. A learning curve approach is used to project cost reduction as a product matures from pilot production, low production quantities, medium production and eventually to high production. However, heavy-duty trucks are not built in production quantities as large as light-duty trucks and passenger cars. As a result, special component prices should be higher for the heavy-duty truck components. Since the approach to costing relied heavily on the determination of costs through the after market price of analogue automotive hardware, it is important to identify truck-only components and adjust their prices to reflect a lower production quality.

The definitions and classifications of heavy-duty based trucks as used in this cost analysis were taken from an earlier EPA-sponsored effort on particulate control technology.(3) These classifications are shown below.

Class	
Light-Heavy	- Heavy pickup trucks, vans, panel vans, and recreational vehicles from 8,500 to 14,000 pounds gross vehicle weight (GVW).
Medium-Heavy	- Straight trucks and all other heavy-duty vehicle bwtween 10,000 and 45,000 pounds GVW except transit buses and line haul trucks.
Heavy-Heavy (Line-Haul Trucks)	- Large, heavy, very powerful trucks used for long-distance freight and similar applications. Almost all are heavy tractor-trailor and double trailer combinations, 40,000 pounds GVW and up.

Unfortunately, the approximate number of diesel trucks in each classification was not provided in the cited reference, and the classifications combined the more standard Motor Vehicle Manufacturers Association classes, often in the middle of a classification. For estimating purposes, an approximate production quantity of diesel trucks by class was generated using the U. S. truck registration by make and GVW for 1982 (4) and are shown below.

Class	Approximate Production Quantity	No. of Major Manufacturers	Approximate Average Production
Light-Heavy (6,000-14,000 GVW)	27,163	4	7,000
Medium-Heavy (14,000-33,000 GVW)	119,3000	7	17,000
Heavy-Heavy (33,000 and up GVW)	73,285	11	6,700

The production quantity by class can be compared to a typical annual automotive production capacity. For example, the Chevrolet Division of General Motors produced 139,063 full-size passenger vehicles with V-8 engines and 173,944 V-8 diesel passenger cars in 1982.(4) Comparing these production quantities against the production of a certain class of heavy-duty diesel vehicle allowed calculation of a production ratio factor as shown below.

$$\text{Production Ratio Factor (prf)} = \frac{\text{GM Chevrolet V-8 engine production}}{\text{production by average medium-heavy duty manufacturer}}$$

$$= \frac{139,000}{17,000}$$

$$= 8.176$$

which represents approximately 3 "doublings," ($2^3=8$). Therefore, according to previous work(2), an approximate total cost adjustment can be calculated as:

$$\text{Cost/Component} = \frac{\text{Component Cost, \$}}{[\text{Adjustment Factor}]^n}$$

where n = number of production "doublings"

Using an adjustment factor of 0.80 on the total cost (2), the per dollar cost of a medium-heavy duty component can be calculated as:

$$\text{Cost Component} = \frac{\$1.00}{(0.80)^3} = \frac{\$1.00}{0.512} \cong \$2.00$$

Therefore, if an analogous part was manufactured to support the production of a comparable quantity of vehicle units, a similar part produced only for the lower production quantity of a manufacturer's line of medium-heavy duty trucks would cost approximately twice as much.

The total cost adjustment factor (TCAF) can be directly applied to the already defined RPE to arrive at the proper RPE for the lower production case of heavy-duty vehicles. For this short-term costing effort the following cost adjustment factors were utilized:

Truck Classification	Production Radio Factor	Total Cost Adjustment Factor (TCAF)
Light-Heavy Duty	20	2.56
Medium-Heavy Duty	8	2
Heavy-Heavy Duty	21	2.59

These factors were taken from Figure 2 which was developed from information in Reference 2. The production ratio noted in the figure is the ratio of an analogous automotive production rate and an assumed truck production rate. The reader is cautioned that these factors should be applied only to those items that are unique to the component assembly for truck production. Standard hardware, that is, hose clamps, standard sensors, and other non-truck unique hardware, should not be escalated.

The RPE used in this costing exercise can be represented as:

RPE = MPE [1.8] [TCAF for vehicle category, if applicable]

This approach will become more evident in the following sections of the report.

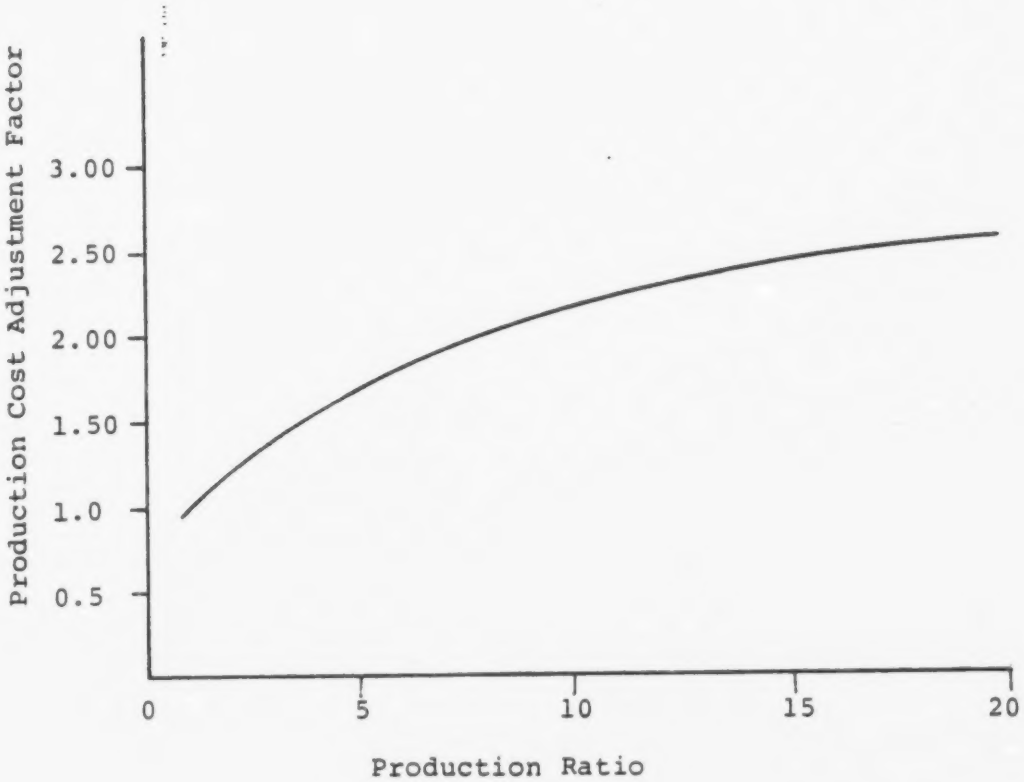


FIGURE 2. ADJUSTMENT FACTOR VS. PRODUCTION RATIO

Source: Developed from Reference 2

II. SYSTEM 1 - DIESEL FUEL BURNER REGENERATION COMPONENTS

A. Identification of Components

The ceramic monolith, wall-flow trap system uses an external, diesel fuel-fired burner to raise inlet gas temperature to the level required to initiate trap regeneration. The principal components of this system are the injector which admits fuel to the burner, the engine-driven blower which supplies a controlled flow of air to support combustion in the burner and possibly a fuel injection pump to supply adequately pressurized fuel to the burner fuel injector. The last item may not be required. The engine fuel transfer pump in most diesel engine fuel systems develops about 40 psig (5) which may be sufficient to generate adequate fuel atomization. If the auxiliary (regeneration burner) injection pump is required, it will probably be driven from the engine fuel injection pump.

Figure 3 illustrates the postulated system and the following paragraphs describe its key components in greater detail.

Injector - The regeneration system fuel injector is envisioned as an electric solenoid type, similar to those used in port fuel injection systems for SI engines. Such an arrangement would separate the trap regeneration system from the high-pressure side of the engine fuel system, since an injector of this type could probably operate at fuel transfer pump pressure (approx. 40 psig). This would obviate the need for modifications to the engine fuel injection pump(s), and eliminate the need for a separate injection pump and simplify engine maintenance. Moreover, an electric solenoid injector is highly controllable with respect to delivery rate by electronic modulation of the "ON" pulse width. It is also capable of rapid response to electronic control inputs. These features are important for close control of the regeneration rate which, in turn, is necessary for effective trap overtemperature protection.

Regeneration Burner Blower - To provide a controllable supply of combustion air for the regeneration process, an engine-driven

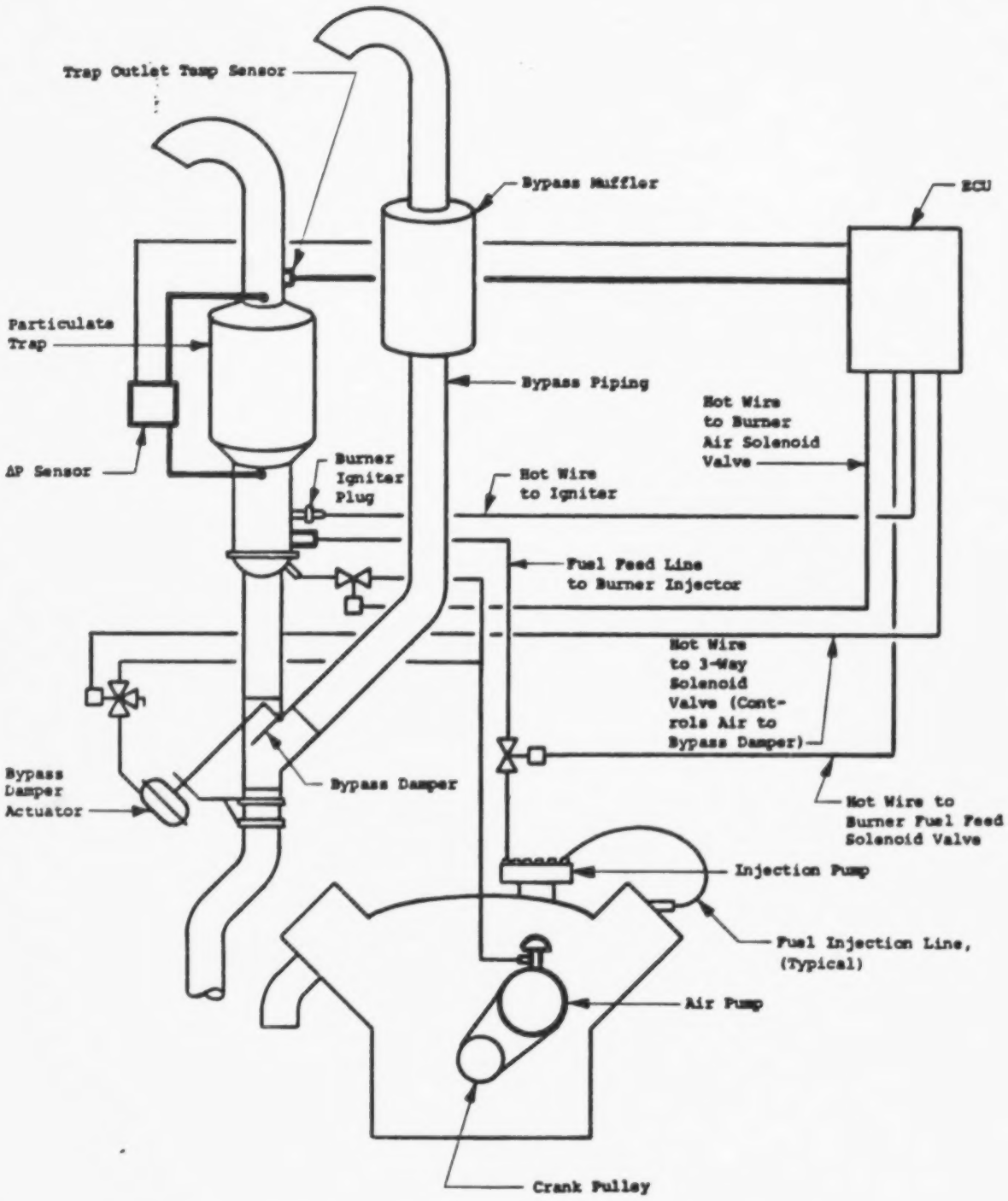


FIGURE 3. DIESEL FUEL BURNER REGENERATION SYSTEM SCHEMATIC DIAGRAM

blower is required. This component is envisioned to be very similar to the engine-driven "air pumps" which have been used with both catalyst-based and non-catalyst SI engine emission control systems for almost two decades. It would perhaps have greater air delivery capacity and develop slightly greater discharge pressure. Neither of these differences is deemed to require significant modification of the basic blower design. The blower would probably also employ similar "dress" components for output control as its SI engine counterpart. These would include a check valve to prevent exhaust backflow through the blower and a diverter valve to direct output away from the trap on an overtemperature signal.

Option A: Supplementary Burner Pump - It is possible that effective fuel atomization by the injector would not be obtainable at the (approximately) 40 psig pressure typical of heavy-duty diesel vehicle transfer pumps. In this case, a separate injection pump might be necessary. Since adequate atomization is attained at 100 psi pressure drop across the nozzles of domestic oil burning systems, it is assumed that the injection pump could be a small piston- or gear-type positive displacement unit driven by a DC electric motor. Alternatively, it would be integrated with the engine fuel injection pump or other mechanical engine system to the extent of being driven by a quill shaft or other mechanical power take-off. In this case, regeneration injection pump output could be controlled by solenoid valves, recirculating pump output when it was not needed.

B. COST ESTIMATE

Table 1 lists the estimated costs for the diesel fuel burner trap regeneration system components indentified as part of this section.

TABLE 1. COST ESTIMATES FOR DIESEL FULL BURNER REGENERATION SYSTEM

COMPONENT	DESCRIPTION	ESTIMATED RETAIL PRICE RANGE	ESTIMATED MANUFACTURER PRICE EQUIVALENT (MPE) RANGE	RETAIL PRICE EQUIVALENT (RPE)	RETAIL PRICE EQUIVALENT WITH PRODUCTION VOLUME AND COMPONENT SIZE ADJUSTMENTS			SOURCE(S)
					LIGHT-HEAVY DUTY	MEDIUM-HEAVY DUTY	HEAVY-HEAVY DUTY	
Fuel Injector	Electro-mechanical fuel injector activated by a 12 volt current source.	$40-$60	$8-$15	$14-$27	$14-$27	$14-$27	$14-$27	1,6,7,17
Fuel Pump (Option A)	High pressure pump driven off the injection pump or an accessory shaft.	$35-$80	$7-$20	$13-$36	$13-$36	$13-$36	$13-$36	1,6,7,11,14
Combustion Air Blower	Sliding vane air pump driven directly by the engine.	$150-$200	$30-$40	$54-$72	$54-$72[a]	$108-$146[b]	$140-$187[b]	1,6,7,17

[a] Similar in size and capacity to automotive air pump, adapted hardware.

[b] Assumes design upgraded and produced to heavy-duty diesel vehicle manufacturer specifications.

III. SYSTEM 2 - TURBO BYPASS VALVE AND PIPING COMPONENTS

A. Identification of Components

A turbocharger bypass valve has been chosen by Daimler-Benz for use with their particulate trap oxidizer system which is used on 1985 California model turbocharged diesel passenger vehicles. The bypass valve assists regeneration of the particulate trap by bleeding some compressor discharge air back into the compressor inlet under certain high boost conditions. Recirculating the inlet air raises its temperature and lowers the air/fuel ratio seen by the engine at high loads. The combination of higher inlet air temperature and lowered air/fuel ratio tends to cause increased exhaust gas temperatures, thus facilitating particulate trap regeneration.

Figure 4 illustrates the tubocharger bypass valve Mercedes-Benz intends to use on their 1985 model year California specification diesel passenger vehicles. Not illustrated in Figure 4 is the piping required to transfer the air from the bypass valve back into the inlet of the turbocharger. The bypass valve and piping are the two main components which are the subject of this cost projection analysis.

Turbo bypass valves can be designed to bypass air according to intake manifold pressure (a "pop-off" type valve) or under computer control using a vacuum actuated diaphragm assembly in conjunction with a "butterfly" type valve. Pop-off valves are held on their seats by spring pressure and open when air pressure acting on the valve head overcomes the spring force acting on the valve. The advantages of pop-off valves are simplicity of operation and low cost. The disadvantages of pop-off valves include "on-off" type of operation and susceptibility to sticking. Computer controlled, diaphragm actuated butterfly type valves can be controlled to give close to linear response with positive operation. The major drawback to these types of valves is their cost compared to pop-off type valves.

The turbo bypass piping must be able to withstand operating pressures of up to around 20 psig and temperatures of up to 300°F. In most cases, the turbo bypass piping can be made to be

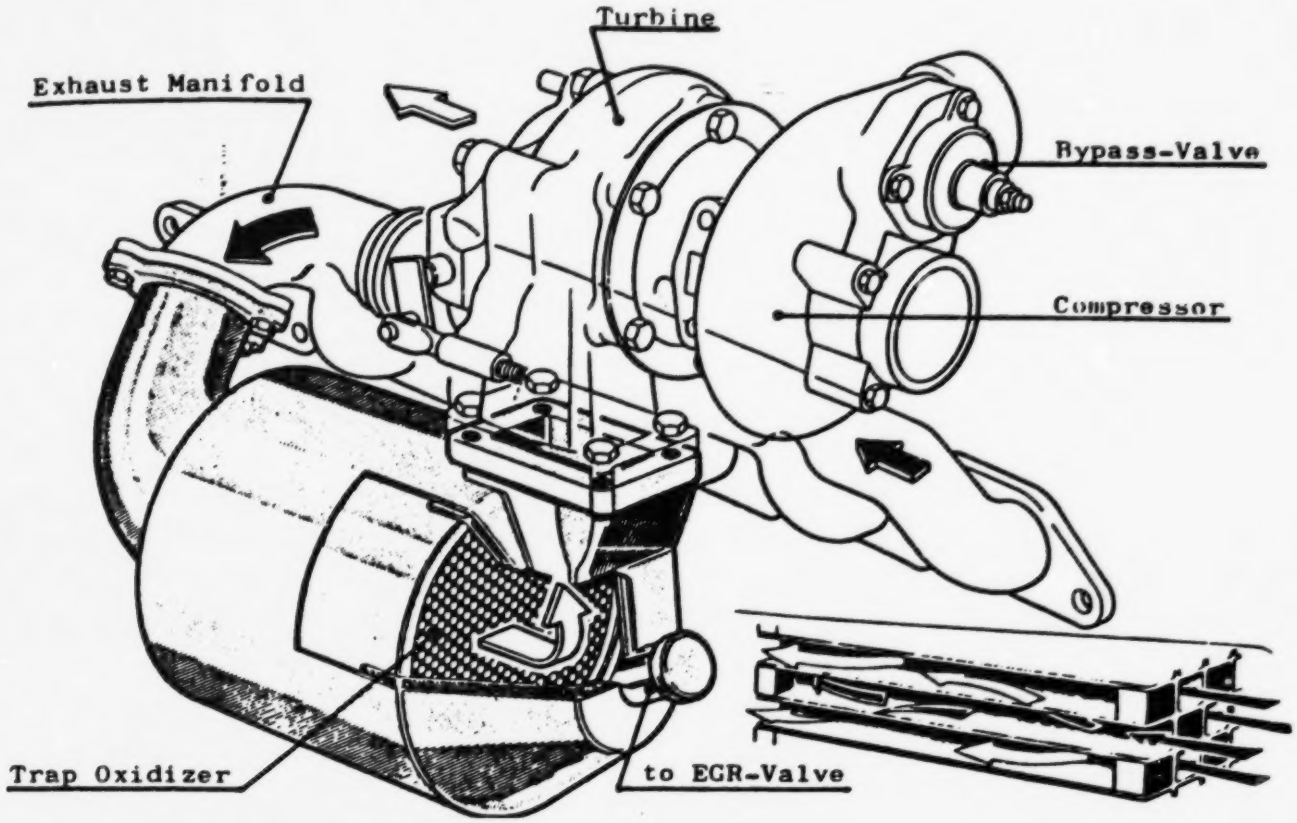


FIGURE 4 ILLUSTRATION OF TURBO BYPASS VALVE USED IN CONJUNCTION WITH A SELF-REGENERATING PARTICULATE TRAP OXIDIZING SYSTEM

Source: U.S. Environmental Protection Agency, Motor Vehicle Emissions Laboratory, Ann Arbor, MI, September, 1984.

18 inches long or less. For these instances, silicone rubber hose can be used similar to the flexible hose sections used downstream of the turbocharger compressor in turbocharged spark ignition vehicles. For longer lengths, steel piping is likely to be used, connected by short sections of silicone rubber hose. Standard hose clamps should be adequate to secure the rubber hose sections to the engine/turbocharger system.

For either type of valve, the inclusion of a turbo bypass valve and piping represents additions and modifications to existing turbocharged diesel engines. The valves and piping are additional

hardware. Modifications of the intake system will be required to accommodate the bypass valve and incorporate the piping. The size of the valves and the diameter of the piping will be somewhat dependent on the displacement of the engine. However, it is likely that one size of valve and diameter of piping could adequately serve the heavy duty class of vehicles.

B. Cost Estimates

The estimated cost ranges for pop-off and butterfly type turbo bypass valves, piping, and engine modifications are listed in Table 2. It should be kept in mind that the computer controlled butterfly type bypass valve requires a microprocessor plus engine speed, load, and bypass valve angle inputs to operate properly. These components were not included within the scope of this section (Section V contains cost estimates for these items).

TABLE 2. COST ESTIMATES OF TURBO BYPASS VALVES AND PIPING

COMPONENT	DESCRIPTION	ESTIMATED RETAIL PRICE RANGE	ESTIMATED MANUFACTURER PRICE EQUIVALENT (MPE) RANGE	RETAIL PRICE EQUIVALENT (RPE)	RETAIL PRICE EQUIVALENT WITH PRODUCTION VOLUME AND COMPONENT SIZE ADJUSTMENTS			SOURCE(S)
					LIGHT-HEAVY DUTY	MEDIUM-HEAVY DUTY	HEAVY-HEAVY DUTY	
Pop-Off Type Turbo Bypass Valve	Cast Aluminum Housing, Light Steel Valve, Steel Spring, Machining Operations Required	$10-$20	$2-$5	$4-$9	$10-$23	$8-$18.0	$10.50-$23.5	13,14,16,17
Butterfly Type Turbo Bypass Valve	Cast Aluminum Housing With Bushings for Steel Throttle Shaft Holding Brass Butterfly Valve; Very Similar to Fuel Injection System Throttle Assembly	$150-$250	$30-$60	$54-$108	$138-$276	$108-$216	$140-$280	13,14,16,17
Computer Controlled Vacuum Diaphragm Actuator	Cast Iron or Aluminum Base Plate, Stamped Steel Disphragm Housing, Rubber-Based Diaphragm, Steel Actuator Rod	$50-$70	$10-$18	$18-$33	$18-$33[a]	$18-$33[a]	$18-$33[a]	1,6,7,17
Bypass Piping	Silicone Rubber Hose	$8-$15	$2-$3	$4-$5.50	$4-$5.50[a]	$4-$5.50[a]	$4-$5.50[a]	10
Piping Clamps	Standard Steel Hose Clamps	$1	$0.20-$0.25	$0.36-$0.45	$0.36-$0.45[a]	$0.36-0.45[a]	$0.36-$0.45[a]	9,18
Modification of Turbocharger Compressor Housing	Revised Casting Required, Machining of Valve Seat, Drilling and Tapping of Attachment Holes	$40-$60	$8-$15	$14-$27	$36-$70[b]	$28-$54[b]	$36-$70[b]	13,14
Modification of Inlet Hose to Turbocharger	Redesign of Part to Incorporate Fitting for Bypass Piping	$15-$20	$3-$4	$6-$8	$15.5-$26.5[b]	$12-$18[b]	$15.5-$20.5[b]	10,14

[a] No adjustment required; assume direct adaption of current automobile hardware.

[b] No adjustment required for varying size of component.

IV. SYSTEM 3 - CERAMIC FIBER TRAP METAL CATALYST REGENERATION COMPONENTS

A. Identification of Components

The metal-catalyzed, silica-fiber trap system consists of an on-board catalyst reservoir, a catalyst metering device, and a subsystem to inject the catalyst into the vehicle exhaust stream so it can be collected on the trap and initiate particulate burn-off. Because the catalyst is a dry crystalline powder, it poses unique problems of storage, metering, and transport.

The system described below postulates that the use of compressed air will be required to fluidize the catalyst sufficient to permit its transport into the exhaust stream. The subsystem envisioned for this function is analogous to the flow control unit of a sand blaster, which must meet a similar requirement. Catalyst metering is accomplished by a device similar to a multi-vane pump in a concentric case. As the vaned impeller rotates, gravity fills the spaces between vanes with catalyst powder from the reservoir. These "units" of catalyst are moved around the periphery of this lock hopper without compressing the powder, which might compact it into untransportable lumps. At the opposite side of the lock hopper case the unit volumes of catalyst spill into a smaller reservoir from which they are aspirated into the feed line by a controlled flow of compressed air from the vehicle's high-pressure air system.

The key components of this system are illustrated schematically in Figure 5 and are described in greater detail below.

Catalyst Reservoir - This part must store the cuprous chloride (CuCl) trap regeneration catalyst between regeneration cycles. Since the CuCl is stored aboard the vehicle as a dry powder, the reservoir must be capable of isolating it from atmospheric water vapor or the powder may cake. A blow-molded polyethylene bottle with removable top is envisioned, similar generally to a windshield washer solvent bottle. Its lower end will provide a mounting for the catalyst "pump." In some applications, mounting hardware in the form of bands and brackets may be required. In other applications, underhood mounting with sheet metal screws and integrally

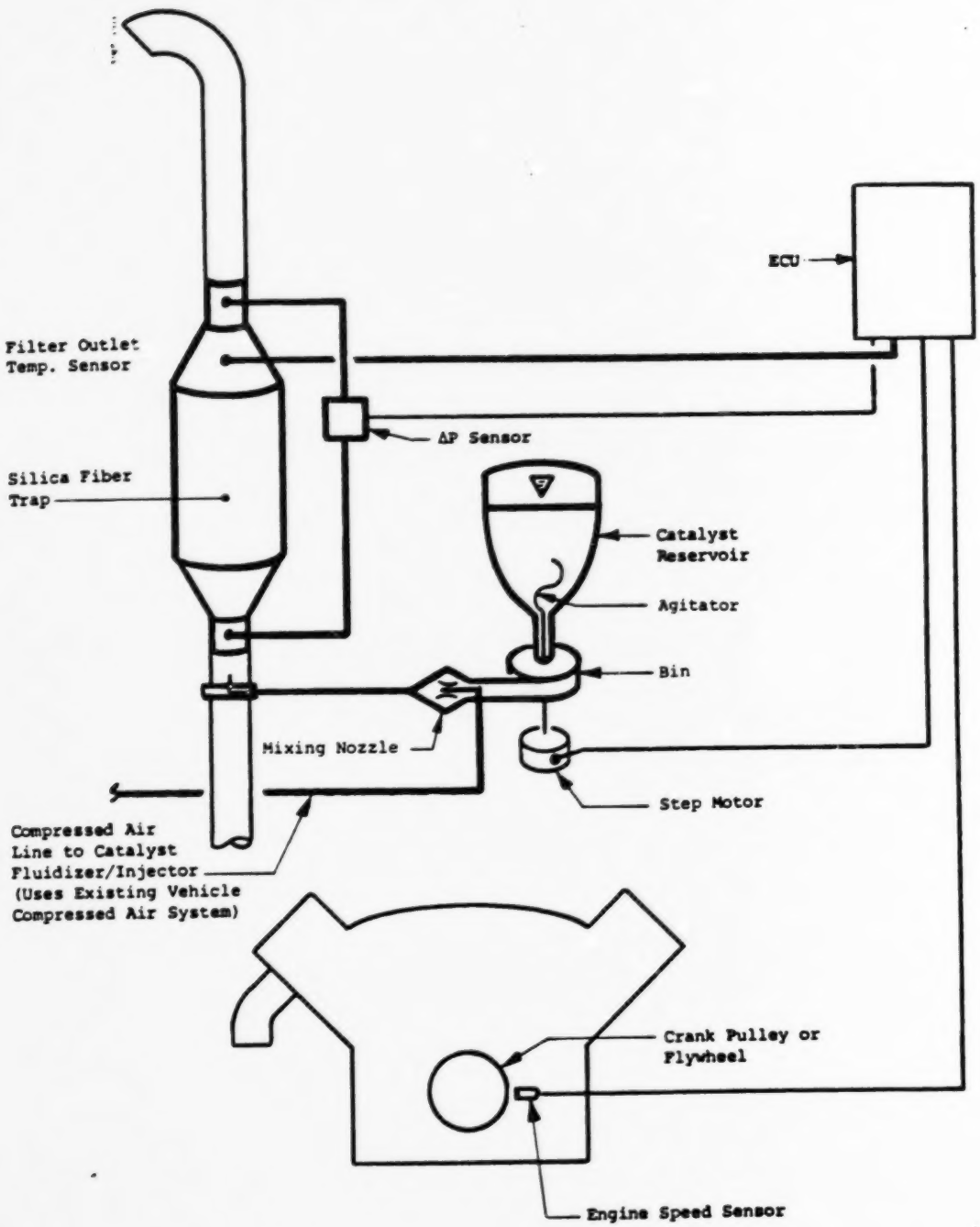


FIGURE 5. CERAMIC FIBER TRAP METAL CATALYST

formed "ears" may be possible, similar to the typical mounting (in LDVs) of windshield washer solvent bottles.

Catalyst "Pumps" - Due to the physical state of the catalyst, the "pump" will more likely resemble a lock hopper with an integral agitator to break up lumps and ensure the delivery of powdered catalyst to the metering lock hopper. The problem of delivering a well dispersed "spray" of powdered catalyst into a heavy duty engine exhaust system at above-atmospheric pressure suggests that compressed air will be used to transport and fluidize the powder. The resulting positive pressure in the catalyst delivery line further argues for a lock hopper-type pump. This will prevent the pressurized air from flowing backward through the pump, unloading its catalyst back into the reservoir. The lock hopper may also obviate the need for a separate check valve to isolate the catalyst reservoir from the exhaust system between regenerations. Some additional means of accomplishing this isolation may be required, however, since accretion of exhaust particulate or collection of exhaust condensate in the catalyst delivery line are obviously to be avoided.

The "pump" is assumed to be electric motor-driven and, as indicated earlier, to incorporate an agitator shaft extending up into the reservoir. Metering of the catalyst can be accomplished readily with the pump since the pump is essentially a positive displacement device. This will probably require a stepping motor drive system.

Silica Fiber Trap - This particulate trap concept is proprietary to Mercedes-Benz AG (MBAG) and relatively little is known about it compared to the volume of data that has become available regarding the ceramic wall flow monolith traps that have been developed and tested by Corning Glass. Tubes or "candles" of perforated metal are wound with silica (SiO_2) fibers and arranged in a "can" so that exhaust must pass through the silica fiber fabric on its way to the atmosphere. The can in which these elements are packaged and the supporting perforated metal cylinders are readily envisioned as typical of standard muffler-exhaust system construction in Type 409 stainless steel.

B. Cost Estimates

Table 3 lists the cost estimates for the ceramic trap metal catalyst system components identified in this report. The silica fiber trap material is difficult to cost accurately since the technique(s) by which it is made and wound are unknown. Best engineering judgement was used based on the retail price of similar ceramic fiber matting.

TABLE 3. CERAMIC FIBER TRAP METAL CATALYST SYSTEM COST ESTIMATES

COMPONENTS	DESCRIPTION	ESTIMATED RETAIL PRICE	ESTIMATED MANUFACTURER PRICE EQUIVALENT (MPE)	MANUFACTURER PRICE EQUIVALENT WITH PRODUCTION VOLUME AND COMPONENT SIZE ADJUSTMENTS			SOURCE(S)
				LIGHT-HEAVY DUTY	MEDIUM-HEAVY DUTY	HEAVY-HEAVY DUTY	
Catalyst Reservoir	Blow molded polyethylene container of 1 gallon capacity.	$25	$5	$5	$5	$5	1,6,7,10,17
Catalyst Metering "Lock Hopper"	Plastic revolving multi-bin design	$115	$23	$23	$23	$23	10
Stepper Motor	12 Volt DC motor	$45	$9	$9	$9	$9	8,12
Fluidizer/ Injector	Nozzle with suction head and required fittings to mate to lock hopper and air supply.	$25	$5	$5	$5	$5	9
Silica Fiber "Candle" Trap	Stainless steel cylindrical housing with ceramic fiber wrapping over an inner core of horizontal perforated stainless steel tubes.	$285	$57[a]	$57[a]	$83[b]	$109[c]	1,6,7,11,14

[a]Estimate based on trap size of 11 liters for light-heavy duty vehicle class.

[b]Estimate based on trap size of 21 liters for medium-heavy duty vehicle class.

[c]Estimate based on trap size of 39 liters for heavy-heavy duty vehicle class.

V. SYSTEM 4 - GENERAL COMPONENTS FOR TRAP OXIDIZER SYSTEMS

A. Identification of Components

This section addresses general components which are likely to be used as parts of various particulate trap oxidizer systems. These components are primarily sensors which could be used to monitor and control the regeneration process. The components which were analyzed are listed as follows:

- Exhaust Backpressure Sensor
- Exhaust Temperature Sensor
- Turbo Bypass Valve Control
  - o Engine Speed
  - o Rack Position
  - o Throttle Angle
  - o Electronic Control Unit

Exhaust Back Pressure Sensor - It is assumed that the exhaust back pressure sensor will be installed before the particulate trap. This sensor will be used to trigger trap regeneration or to indicate to the vehicle operator that the particulate trap system requires attention. Based on the design of other vehicle sensor components, it is most likely that this device will be of simple design and only indicate whenever the back pressure has passed a certain threshold value rather than continuously generating an output signal directly proportional to back pressure.

The design envisioned is one capable of operating in an installed position that is between the turbocharger and particulate trap. This installation position, downstream of the turbocharger, will require a sensor that will function over a lower range of probable back pressure. The sensor assembly would be composed of a cast iron housing allowing exhaust pressure to come into contact with a stainless steel diaphragm mounted within the housing. On the atmospheric pressure side of the diaphragm or bellows, an actuating rod/spring assembly, or other simple mechanical

system would transmit the back pressure-generated excursion of the diaphragm or bellows to a single spring metal-disk switch assembly. This switch assembly would be thermally isolated from the diaphragm housing and other exhaust system components. The metal-disk switch would be normally open, and would be closed only when the back pressure exceeded the design threshold.

Exhaust Temperature Sensor - An exhaust temperature sensor could be used to initiate and/or control regeneration of particulate traps. Exhaust temperature sensors could be used with both the diesel fuel burner and metal catalyst injection type regeneration systems discussed in Sections II and IV.

Exhaust temperature sensors have been developed for measurement purposes and are used currently on some heavy duty turbocharged vehicles. The sensor is essentially a heavy duty thermocouple. Signal conditioning of the sensor output is required to obtain a simple readout of temperature or when used for control purposes. The ECU (electronic control unit) which controls trap regeneration should be able to incorporate the exhaust temperature sensor output directly into its control scheme. Both initiation and control of regeneration to prevent overtemperature of the trap could be controlled using an exhaust temperature sensor.

Engine Speed - Engine speed sensors have been developed in the past few years to accurately monitor engine speed. The sensor usually takes the form of a stationary magnetic pickup and a protrusion on the engine crankshaft pulley or flywheel. An electrical pulse is created when the metallic protrusion sweeps past the magnetic pickup. The output of the sensor can be conditioned and read directly by an ECU for use to control a turbo bypass valve or to initiate and/or control trap regeneration.

Rack Position - The position of the rack of a diesel engine is a direct indication of the load the engine is under. Typically, for a constant engine speed, a diesel engine will have increasing exhaust temperature with increasing engine load. Thus, rack position is a convenient measure of engine load which could be

used to initiate and/or control trap regeneration or a turbo bypass valve. Typical automotive-grade position sensors are electrical rheostats providing a voltage proportional to rack position.

Throttle Angle - This sensor is specific to trap regeneration systems employing an ECU controlled turbo bypass valve. The throttle angle sensor tells the ECU how wide a butterfly type bypass valve has opened. This information is necessary to assure that the valve is opened to the desired position at each and every combination of engine speed and load. Typical throttle angle sensors are a circular electrical rheostat which puts out a voltage proportional to the angular opening of the turbo bypass valve.

Electronic Control Unit (ECU) - The ECU monitors all the engine/trap regeneration systems inputs (i.e., engine speed, load, exhaust temperature and backpressure, rack position, etc.) and provides outputs to initiate and control trap regeneration.

B. Cost Estimates

The cost estimates for the general trap control sensors and components identified as part of this section are presented in Table 4. The cost estimates for these components and sensors were developed through direct contact with manufacturers of analogous subassemblies and comparisons to prices of similar automotive parts in high volume production.

TABLE 4. COST ESTIMATES FOR GENERAL COMPONENTS OF TRAP OXIDIZER SYSTEMS (TABLE 4 COMPONENTS

COMPONENT	DESCRIPTION	ESTIMATED RETAIL PRICE RANGE	ESTIMATED MANUFACTURER COST RANGE	SOURCE(S)
Exhaust Back Pressure Sensor	Cast iron housing, stainless steel diaphragm, actuator, rod/spring and snap action switch assembly.	$60-$90	$14.50-$17.50	1,7,11
Exhaust Temperature Sensor	Heavy duty thermocouple without conditioner or readout.	$20-$30	$4-$8	14
Engine Speed Sensor	Magnetic pickup mounted solidly to engine block near crankshaft pulley or flywheel.	$12-$25	$3-$5	1,14
Rack Position Sensor	Linear or radial electrical rheostat	$20-$30	$4-$8	1,14
Throttle Angle Sensor	Radial electrical rheostat.	$20-$30	$4-$8	1,14
Electronic Control Unit	Microprocessor with Read Only Memory (ROM) to monitor and control trap regeneration; electronics encased in epoxy in an aluminum housing.	$100-$250	$20-$60	1,14

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